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Creation of future compact urban form scenarios of Tokyo in combination with adaptation policies

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Abstract

Studies have suggested the importance of implementing climate change mitigation and adaptation measures in combination with considering possible co-benefit and trade-off among them. However, quantification of such co-benefit/trade-off at city level is still in its infancy. Accordingly, using a micro zone level spatial explicit land use model which we have developed, this study assesses the co-benefit/trade-off of mitigation measure (compact city policy) and adaptation measure (retreat from high flood hazard areas) from the view point of CO_2 emissions and expected loss due to the damage by river floods. For the assessment of residential CO_2 emissions, this paper utilizes the microdata of National survey of family income and expenditure. The results suggest the importance of careful planning to create compact city to avoid trade-off. This study was funded by "Research Program on Climate Change Adaptation (RECCA)" of the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan.

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Key words: Land use model, Compact city, Flood hazard, Microdata

1. Introduction

Studies have suggested the importance of implementing climate change mitigation and adaptation measures in combination with considering possible co-benefit and trade-off among them [1, 2]. However, quantification of such co-benefit/trade-off at city level is still in its infancy. Accordingly, using a micro zone level spatial explicit land use model which we have developed [3, 4], this study assesses the co-benefit/trade-off of mitigation measure (compact city policy) and adaptation measure (retreat from high flood hazard areas) from the view point of CO_2 emissions and expected loss due to the damage by river floods.

2. Assessment of CO_2 emissions

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For the assessment of residential CO_2 emissions, this paper utilizes the microdata of "National survey of family income and expenditure" of Ministry of Internal Affairs and Communications, Japan. This survey is conducted in the autumn of every five years since 1959, to investigate households' expenditure, saving, income, etc. This is a quite extensive survey implemented against approximately 60,000 households (hhs, hereafter). We obtained this microdata from the ministry through application with research proposal, and it is fairly a new attempt to analyze the microdata. From this dataset, we use the value of electricity bill (yen) of each hh to assess the indirect CO_2 emission from electricity consumption. Because the data includes ids corresponding to the municipality to which each hh belongs, we can map the value of electricity bill as shown in Fig.1 (left-hand side). According to the "Family income and expenditure survey" of 2006, the average electricity bill for the single-family hhs is 4451 yen, while that for the multiple-family hhs is 9462 yen. Thus, there is a clear difference due to the family types. On top of that, electricity bill may depend on income, number of persons in a hh, building types, urban form, etc. Hence we have to adjust sampling bias to make municipality/micro zone level intensity data. Because the microdata includes many zero values, we constructed the zero-inflated negative binomial regression model to explain the variation of electricity bill with the explanatory variables: number of persons in a hh (+), Floor per hh (+), income (+), dummy variable for detached houses (+), 7 family types defined in [5] (+/–) (Here, "+" denotes the positive coefficient estimates, and "–" denotes negative estimates. All coefficient estimates were statistically significant at 1 % level). By substituting regional average to the model, we have the micro-zone level intensity data (yen/hh) as shown in Fig.1 (right-hand side). There is a clear tendency that intensity value is low in the middle of Tokyo, where single-family type dominates.

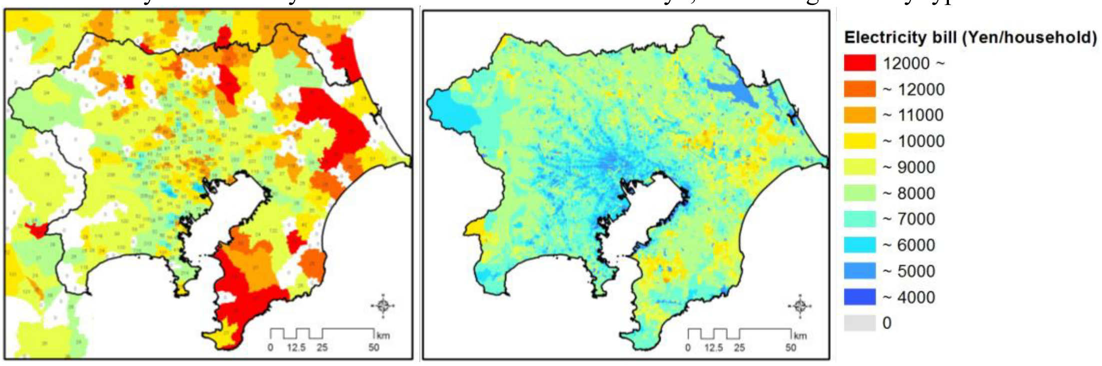

Fig. 1. Left: The average value of electricity bill in 2004 (municipality level observation); Right: micro-district level prediction for 2005. The numbers on the left-hand side figure denote the sample size.

3. Assessment of expected loss due to flood damages

For the economic evaluation of expected loss due to flood damages, Japanese Ministry of Land, Infrastructure, Transport and Tourism has prepared the flood control economy investigation manual [6]. The loss of hh composes *house damage* and *house furniture damage*, which can be calculate as [7]:

$$\begin{aligned} house\ damage &= house\ assetes \times inudation\ area \\ &\times damage\ rate\ by\ inudation\ depth \end{aligned} \quad . \tag{1}$$

$$\begin{aligned} house\ \ furniture\ damage &= house\ \ furniture\ assetes \times inudation\ household \\ &\times damage\ rate\ by\ inudation\ depth \end{aligned} \quad . \tag{2}$$

House assets (yen /m^2), house furniture assets (yen/hh), and damage rate by inundation depth is defined in [6]. In order to define inundation area/household and inundation depth, we use the "possible inundation areas," designated and published by MLIT in around 2001 (Fig.2) (National Land Numerical Information download service). The figure represents the areas which may be inundated by river flood. Once *house damage* and *house furniture damage* is calculated, it is multiplied by return period, and transformed to the present value with social discount rate 4%. The expected loss is calculated by summing it up to the next 50 years from 2005.

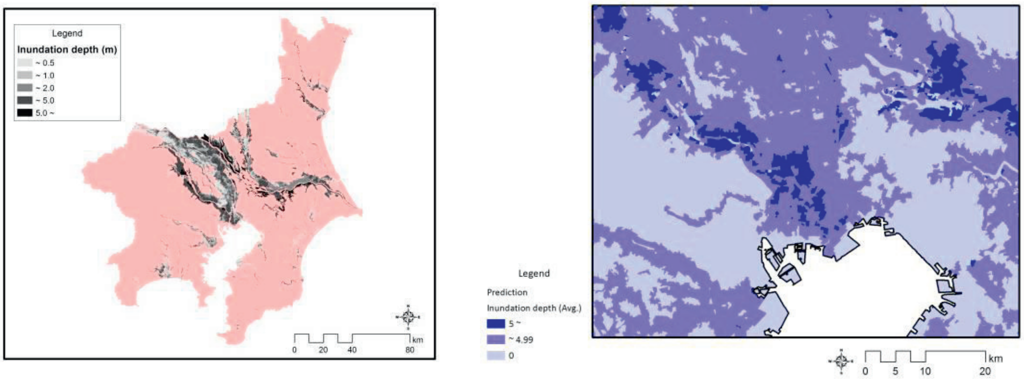

Fig. 2. Possible inundation areas (hazard map) of the Tokyo metropolitan area

4. Spatially explicit land use model

For creating future compact urban form scenarios, we use the spatially explicit land-use model which we have developed in [3, 4]. The structure of the model is described in Fig.3. It is a multi-market static economic equilibrium model based on urban economic theory. The major assumptions of this model are as follows: [1] There exists a spatial economy whose coverage is divided into zones *i*. [2] The total number of each household type *j*, say H_j in the metropolitan area is given (closed city). Households belonging to the same type *j* have identical preferences. [3] The society is composed of three types of agents: households, developers, and absentee landlords. The behavior of each agent is formulated on the basis of microeconomic principles, that is, utility maximization by households and profit maximization by developers and absentee landlords. [4] The households choose their locations in accordance with maximized utility. [5] There is one residential land market and one residential (building) floor market in each zone. These markets reach equilibrium simultaneously. The model can output a set of variables which describe a real urban economy such as distribution of locators (households), distribution of land rent and building floor rent, land and building floor area, etc. The number of zones in our study area (the Tokyo metropolitan area) is 22603.

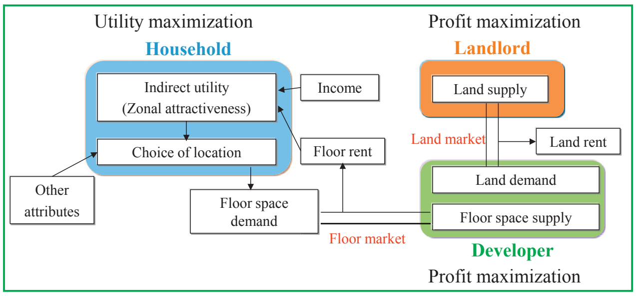

Fig. 3. Structure of our land use model

5. Creation of future compact urban form scenario for 2050

Using the model explained in section 4, here we create three urban form scenarios for 2050—BAU (dispersion city) scenario and two compact city scenarios. Future value of each 7 types of household are projected using the trend extrapolation method, and in the dispersion scenario, the value is allocated based on the current share [5]. For the compact city scenario, the proximity of workplace to home is important for reducing trip length. Hence we quantified the degree of spatial agglomeration of office space using a spatial clustering technique, and defined it as urban center zones [3]. We subsidized these urban center zones by 120000 yen/year, referring to the policy of Toyama city (compact scenario). However, compact urban form not necessarily leads to the reduction of natural disaster risk. Hence we consider the scenario where only the zones whose average inundation depth is less than 5m is subject to the subsidy, which we call "combined" scenario. These three scenarios are assessed from the CO_2 emission (sec.2) and flood risk (sec.3) perspective. The total electricity bills (proxy to CO_2 emission) under these three scenarios are dispersion: 76.63 B$, compact: 76.68B$, and combined 76.67B$, respectively (1$=100yen). The differences were slight, but worsened by compact city scenarios. This is because population moves to high-intensity zones in some areas. The result suggests the possibility that compact city constructed for reducing trip length may raise the CO_2 emission from residential sector. Hence careful planning to avoid such trade-off is quite important. Fig. 4 shows the differences in projected population (left: compact – dispersion; right: combined – dispersion). We can find that population of high risk zones may decrease in combined scenario. The projected change of flood damage by compact and combined scenarios (compared to dispersion scenario) is –7.2B$ and –30.4B$, respectively. The result suggests that just a careful selection of subsidized area may lead to the big differences in expected loss.

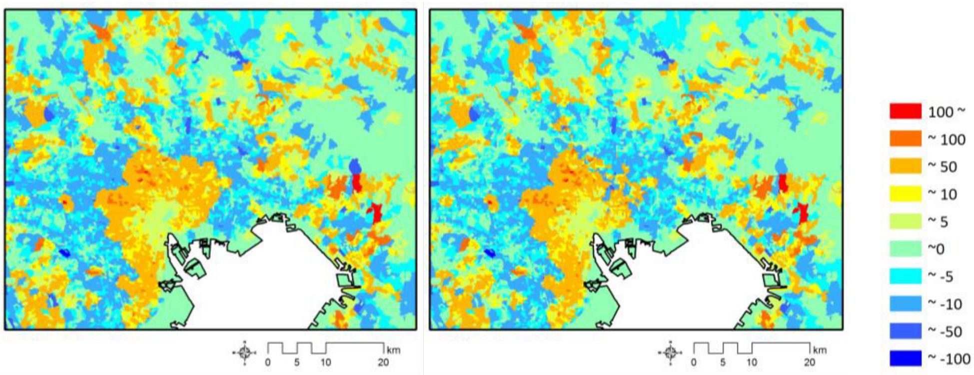

Fig. 4. Differences in projected population (Left: compact – dispersion; Right: combined – dispersion)

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